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AN ELECTRICAL-TYPE INDICATING FUEL FLOWMETER

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September 1939

SR 127

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SUMMARY

An electrical-type meter has been developed for measuring mass rates of flow of gasoline or other nonconducting fluids. Its temperature dependence is small over a large range and it has no known vibrational or viscosity errors. The maximum temperature rise is less than 5° C. The rates of flow, measurable within 1 percent with the present instrument, are approximately 100 to 1,000 or more pounds of gasoline per hour when a potentiometer is used, or 100 to 300 pounds per hour when a deflection-type meter is used.

INTRODUCTION

Design of an indicating rate-of-flow meter was undertaken by the N.A.C.A. as part of a program that required an accurate, portable fuel flowmeter for use in flight that would be unaffected by temperature extremes, moderate accelerations or changes in fuel characteristics, and could be made remote-indicating. After its manufacture, the flowmeter was tested for 3 months for accuracy and permanence of calibration. A sensitive millivoltmeter or a potentiometer was used for an indicator. This flowmeter was used in a test program for several months in such a manner as to show any inaccuracy as soon as it developed. No inaccuracy was found until the meter was damaged by improper operation. A second model with twice the number of couples has been designed to use a relatively rugged stock model microammeter as the indicator.

DESIGN AND DESCRIPTION

The meter described is similar in principle to the Thomas (references 1 and 2) and other meters that measure a temperature difference created in the fluid by the addition of electrically generated heat. (See figs. 1, 2, and 3.) The heat input is fixed and the temperature difference developed is read as a measure of the rate of flow. In practice, current that passes through a resistance-type heater is regulated at a fixed value. The values of the heater resistance and of the current fix the

temperature change developed in the stream according to the relation

$$\Delta T = \frac{k I^2 R_0 (1 + \beta t)}{\text{lb./hr.} \times (\text{sp. heat})_0 (1 + \alpha t)} \quad (1)$$

where ΔT is the developed temperature difference.

k , a constant.

I , heater current.

R_0 , resistance of heater wire at temperature T_0 .

β , the temperature coefficient of resistance of heater wire.

$t = (T - T_0)$, temperature variation from reference temperature.

T_0 , the reference temperature corresponding to R_0 and $(\text{sp. heat})_0$.

lb./hr., pounds per hour flowing.

α , the temperature coefficient of specific heat.

The value of β should be chosen equal to α to eliminate the temperature dependence. This practice may be varied, however, to give other results as desired; e.g., volume rate-of-flow indication may be found by including the expansion coefficient of the fluid and by choosing a suitable value of β . The instrument described is made to indicate mass rate of flow.

Thermocouples are used to indicate the temperature difference developed because both sensitivity and temperature independence of the indicating apparatus are required; no other method of temperature indication is satisfactory over the fuel-temperature range. It is necessary, when handling volatile liquids with this type of meter, to limit the temperature difference developed to avoid "vapor lock" in the case of the highest temperature and the lowest barometric pressure likely to be encountered. The maximum temperature difference in the present instrument was arbitrarily set at 5°C . and normally does not exceed 2°C . A sensitive measuring apparatus is therefore required. Special

care was taken in the choice of thermocouple material, in order that the microvolts per degree would be approximately constant over the gasoline-temperature range. The internal resistance of the thermocouple circuit was kept as small as practical, without allowing too much heat loss along the thermocouple wires, to permit the use of either a millivoltmeter or a potentiometer for an indicator. A multiple thermocouple of 250 pairs of Chromel-Alumel alloys is used to obtain a high value of volts per degree. The short distance (approximately 1/2 inch) between the hot and cold junctions of these couples is made practical by a special method of electrical welding (reference 3). Both thermal and electrical insulation are provided by the use of heavy bakelite walls and partitions. A metal case over the bakelite provides safety and permanence of threaded connections.

ACCURACY

Potentiometer indicator.— When a potentiometer is used as the indicator, the items of temperature dependence are:

1. E.m.f. per degree of the couples.
2. Temperature difference generated.
 - a. Specific heat of the fluid.
 - b. Resistance of the heater.

Item 1 amounts to less than 2-1/2 percent in 100° C., and item 2b compensates item 2a within 1 percent in 100° C., so that the calculated temperature dependence cannot exceed 3-1/2 percent in 100° C. change in fuel temperature and could be reduced to zero by balancing item 2 against item 1.

The use of a small portable potentiometer allows readings accurate to within 1 percent of the smallest voltage used. Theoretically there is no upper limit to the rate of flow that can be measured by this method since increasing either input wattage or the potentiometer sensitivity extends the range. The lower limit of rate of flow is set by the gradual loss of accuracy caused by fluctuations of the indicated temperature below approximately 150 pounds per hour. These fluctuations are caused by the poor flow characteristics in the clearance space required for the maximum rate of flow.

An extended calibration of the first flowmeter, designed to have a range of 60 to 600 pounds per hour, at one value of input current indicated the accuracy to be as follows: from approximately 150 to 600 pounds per hour, the accuracy was that of regulating the flow; above 600 pounds per hour, where the e.m.f. generated is less than 1.50 millivolts, the accuracy was that of reading the potentiometer (0.01 mv sensibility); from approximately 150 to 60 pounds per hour the fluctuation gradually increased the reading error to the design limit of ± 1 percent; from 60 to 20 pounds per hour, the error increased to ± 3 percent.

Calibrations over a 30° C. range of temperature showed no appreciable change, and subsequent use in a test program has shown continued accuracy over a period of several months.

Deflection-type indicator.— In addition to the foregoing items, there are three others present when a deflection-type meter is used, and one compensating item has been introduced as will be shown. These four additional items are:

1. Resistance change of the couple circuit.
2. Resistance change of the indicating instrument.
3. Sensitivity change of the indicating instrument.
4. Sensitivity change of the current-setting apparatus.

Item 1 varies with the fuel temperature and changes the indication less than 2 percent in 100° C. Items 2, 3, and 4 vary with instrument temperature. Item 3 is small, amounting to about 1 percent in 100° C. for the instruments used.

Since a millivoltmeter without a large temperature error was not available (or was too fragile for hard service), a microammeter was used for the indicator. The effect of items 1 and 2 is to change the current but, since they depend on different temperatures, the effect varies slightly, from 33 to 35 percent in 100° C. Items 1 and 2 are compensated by item 4, which was introduced for that purpose. Compensation is obtained by using the indicating microammeter with proper shunt to adjust the heater current but with an added series resistance of manganin to reduce its coefficient of resistance to one-half the value when the

instrument indicates flow. Since the heat input is proportional to the current squared, the heat varies at the same rate as the indicator-temperature dependence and in the direction to compensate for it. The compensation is complete to within 3 percent in 100° C.

The sum of all the temperature errors, if the gasoline temperature is assumed constant, is between 3 and 4 percent in 100° C. If both gasoline and instrument temperatures vary 100° C., the error may amount to about 7 percent but, if only the gasoline temperature varies, the error is less than 2 percent in 100° C.

In the original form the flow indication from 100 to 300 pounds per hour was readable on the scale to about ± 1 percent or better; from 300 to 600 pounds per hour, the scale was readable to ± 3 percent or better.

An indicating instrument has been developed that has the property of being readable to the same percentage accuracy of flow rate at all parts of the scale. This reading accuracy is about 2 percent. Comparable scales of the two types are shown in figure 4.

Tests made at Wright Field in service indicate the advisability of a heater type that allows more even heating of the fuel, thus reducing fluctuations of the indication. This change replaces the perforated bakelite cylinder in figure 3 with a piece having cylindrically arranged columns on which the heater is wound.

GENERAL CHARACTERISTICS

Calibration curve.-- The inverse relationship of indication and rate of flow as shown in equation (1) is approximated in practice. (See fig. 5.)

Range.-- The range of the present instruments is from about 60 to about 1,000 pounds of gasoline per hour when a potentiometer and one setting of heater current are used. The range can be extended upward by increasing the heater current by the factor $\sqrt{\frac{\text{desired range}}{1000}}$ and calibrating.

The deflection-type meter was designed to cover the range of from 100 to 300 pounds per hour, but its range

can also be changed by the use of factors, as previously outlined, or by substituting another meter having the desired characteristics.

Safety.— As the meter is intended for use with gasoline, tests were made before selecting the type of heater used. Laboratory tests showed that a bare wire immersed in or located near the surface of gasoline would carry without failure the maximum possible current even with no fluid flow. No flames can result until a spark occurs, hence the danger of a fire is considered slight even in the event of an accidental closing of the switch for a fairly long period or the running dry of the fuel line for a period long enough to form a combustible mixture. Experience has confirmed this opinion. A pressure-operated safety switch has been incorporated, however, to avoid damage to the instrument by improper operation.

Attendant apparatus.— A source of power capable of supplying at least 50 watts over the period of the test is necessary. The power may be of any reasonable voltage if the heater is correspondingly changed. A regulating rheostat and a potentiometer or microammeter are also required. An ammeter need not be used if the voltage drop across a fixed resistance is used to adjust the current and the flow indicator is used to measure the drop.

Lag.— The lag or total time required to reach a steady reading after a great change in the rate of flow varies inversely as the rate of flow from a few seconds (when changing from low to high flow) to a maximum of about 40 seconds when changing from 600 pounds per hour to approximately 120 pounds per hour. The time required to reach a steady reading when the heater is turned on varies inversely as the rate of flow and amounts to less than 1 minute in the worst case.

Pressure drop.— The pressure drop across the instrument is nearly proportional to the rate of flow and amounts to about 1 pound per square inch with gasoline flowing at the rate of 1,000 pounds per hour.

Fluid characteristics.— It is believed that when using one type of fluid, such as 87 octane gasoline, the variation of indication caused by fluid characteristics would be insignificant; with a change in the type of fuel from aviation gasoline to iso-octane (2-2-4 trimethyl pentane) the calibration is changed about 3 percent.

No trouble is anticipated from corrosion since only corrosion-resistant materials are used. No corrosion has been observed after about 1 year's immersion.

Weight.- The weight of the entire equipment, less batteries, is about 4-1/2 pounds.

Flight tests.- Preliminary tests have shown that the flowmeter operates satisfactorily in flight. The first instrument built was used in a test program in flight with a potentiometer and, although some trouble in securing balance was experienced owing to galvanometer vibration, reasonably accurate data were obtained. Tests of the millivoltmeter type of indicator showed that the vibration present was small and was caused by vibration of the indicator as a whole. Very rough air changes the flow to the engine and therefore affects the indication of the instrument. Further flight and service tests are being made.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 31, 1937.

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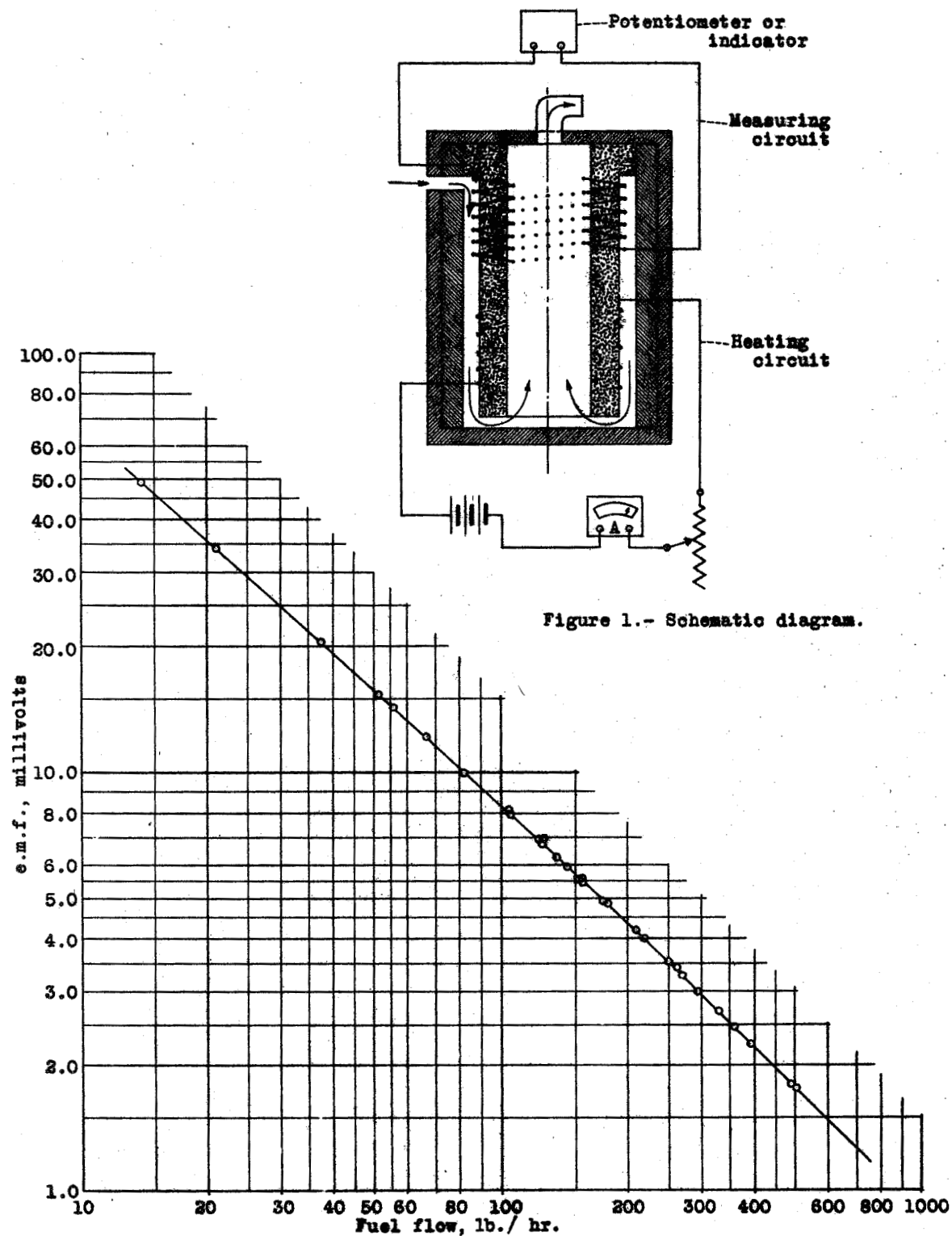


Figure 5.- Calibration curve on potentiometer. Model 1, 87 octane gasoline.

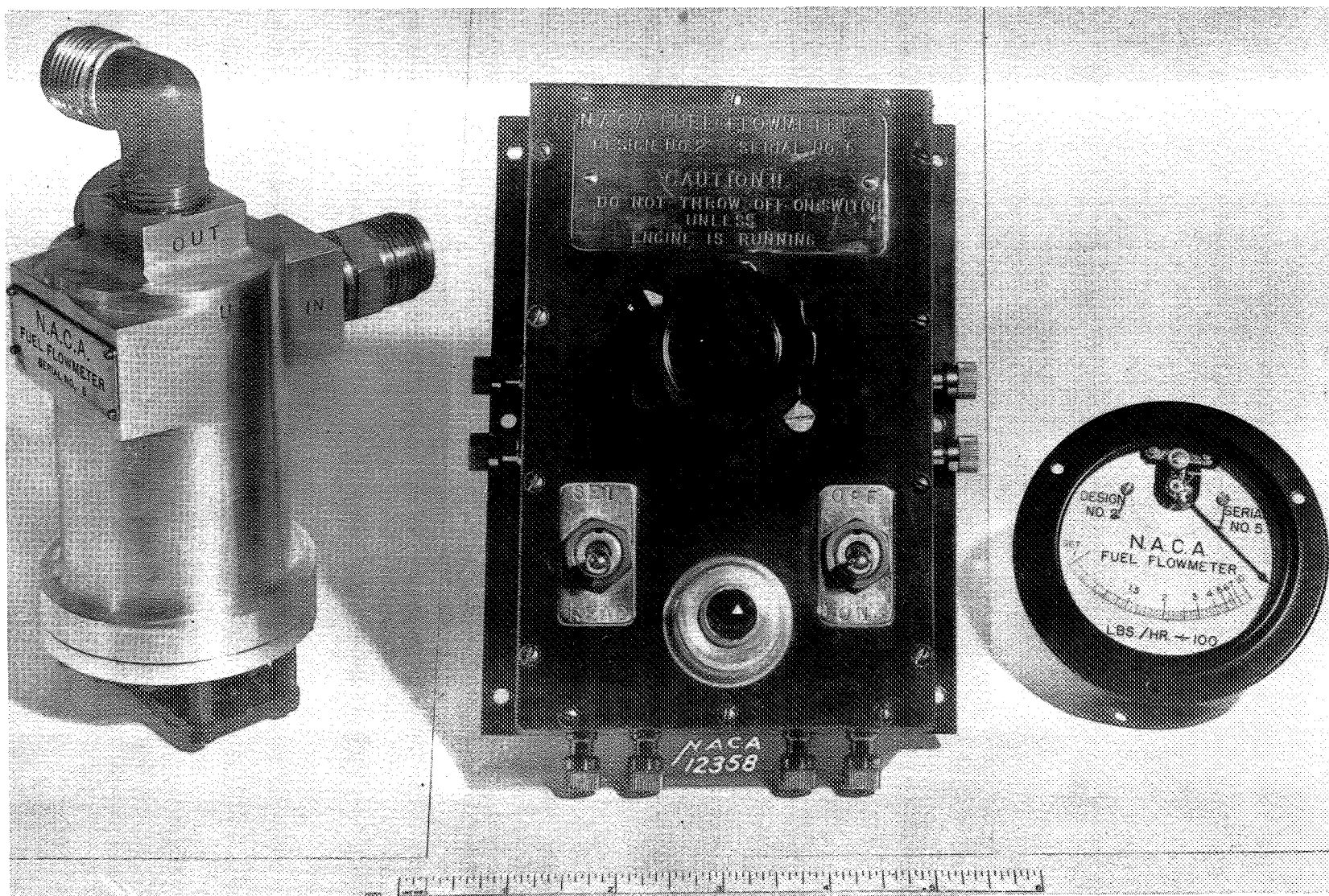


Figure 2.- Assembled meter.

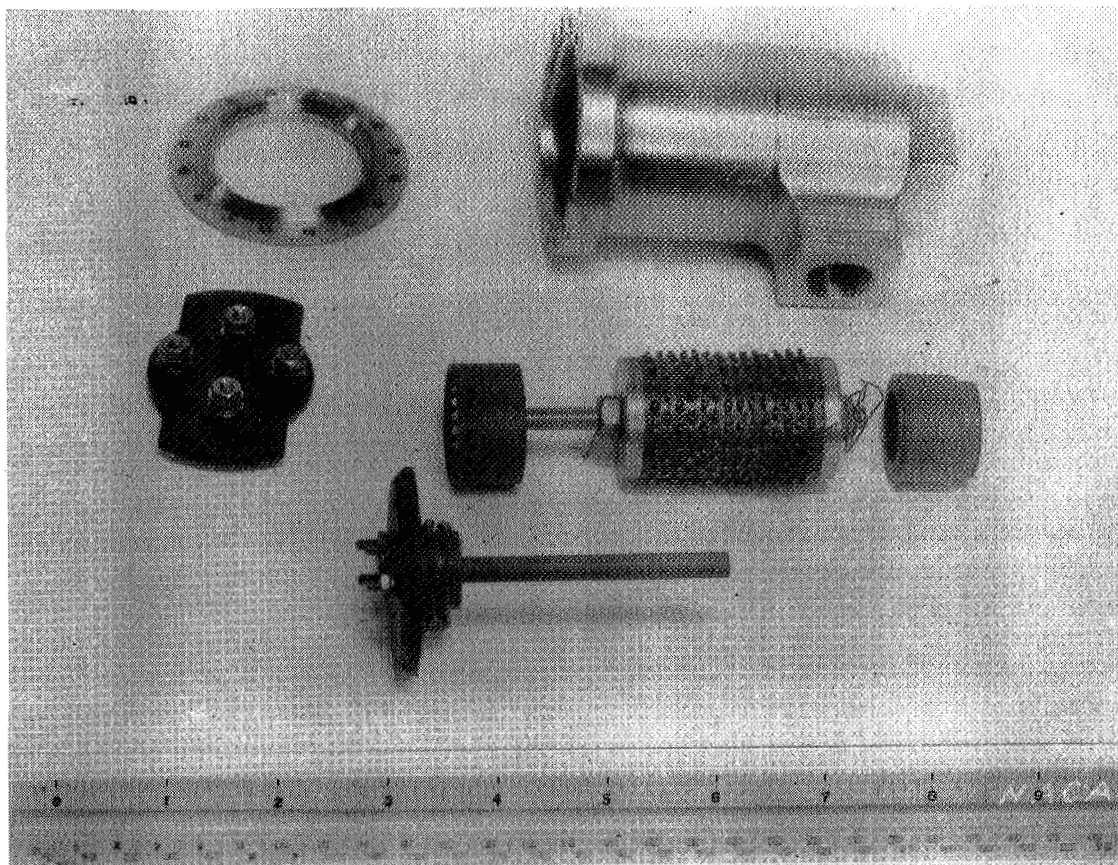
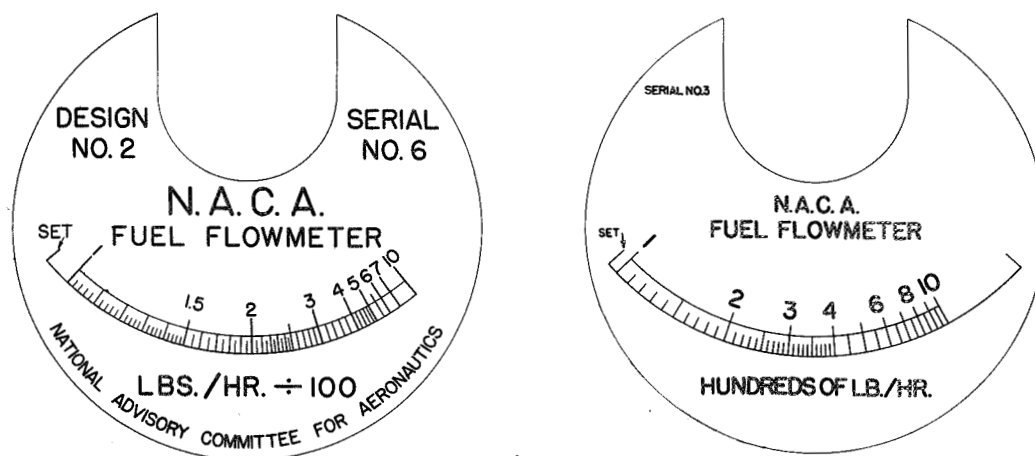


Figure 3.- Unassembled metering unit.



Original

New

Figure 4.- Comparison of scale types.